WAVEFORM BOUNDING AND COMBINATION TECHNIQUES FOR DIRECT DRIVE TESTING

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Abstract

This paper presents various methods to combine a set of measured test signals into a composite signal. The composite signal represents the set of measured test signals by retaining the significant attributes of the original set of measured test data. The composite waveforms are generated to obtain rigorous direct drive waveforms used during aircraft lightning and EMP assessments. Here we propose two techniques and a hybrid method to synthesize the composite waveforms.

Introduction

The use of modern signal processing techniques and algorithms applied to the Electromagnetic Pulse (EMP) spectrum has created new opportunities to use all data gathered during aircraft system level EMP evaluations. Research into combining, compressing and storing transient waveforms is being conducted by the Naval Air Warfare Center Aircraft Division (NAVAIRWARCENACDIV) Patuxent River, Maryland.

During current aircraft EMP evaluations, different simulator polarizations and aircraft configurations are tested to ultimately quantify system survivability. Measurements acquired at the Horizontally Polarized Dipole (HPD) and Vertically Polarized Dipole (VPD) simulators during the system evaluation are stored in the Naval Air Electromagnetic Analysis System (NEMASYS). NEMASYS is a database, analysis tool and report generator used by the test engineers at NAVAIRWARCENACDIV.

Many individual waveforms are acquired during a system level evaluation, of which only 10 % are reused. These 10 % are selected to be inductively coupled onto system cabling during direct drive testing to evaluate system survivability margins. Initially, only the waveform with the highest peak amplitude per individual test point was selected for use during direct drive testing. The other waveforms, as many as five additional at each point, were not used although they contained important information. Through in-house signal processing and the help of the Naval Postgraduate School, transient waveform bounding techniques are being explored. The waveform that contains all important test information from each of the waveforms collected in different polarizations and configurations for each test point, is referred to as a bounded waveform or stress envelope. The purpose of bounded waveforms (stress envelopes) are to: (1) Reduce uncertainty by bounding system/environment interaction; (2) Use all available system response data (polarizations, orientations); and (3) Improve on the aircraft survivability RDT&E process. The bounded stress envelope must accurately reproduce the dominant time and frequency attributes of the original waveforms and must remain stable in the combination process. In the time domain, the bounded nature of the stress waveform is verified by performing a norm attribute analysis. This analysis compares certain attributes of the stress waveform with those of the original waveforms for a close match. The actual bounding process is carried out in the frequency domain. The bounding of the stress waveform is accomplished by performing a wideband signal analysis approach that employs several spectral subband processing techniques. The spectral energy in each subband is selected to ensure that the in-band energy is representative of that of the original waveforms.

Bounding and Combination Algorithms

<u>Sinusoidal Modeling Algorithm</u>

The sinusoidal modeling algorithm as applied to EMP transient signals [1] can be broken into two parts, analysis and synthesis. This modeling algorithm was originally developed for speech signal processing [2] and can be applied to an EMP transient waveform by representing it as a series of sine waves. Figure 1 shows the analysis block diagram.

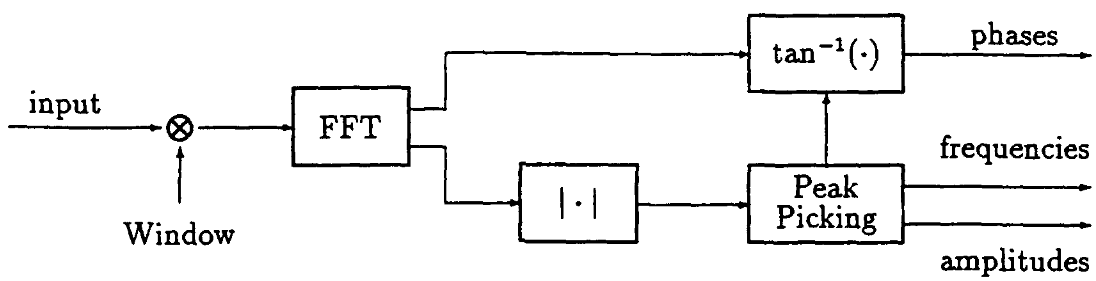

Figure 1: Analysis Block Diagram

The first step in the analysis routine involves breaking the waveform into time domain frames and applying a Hamming window to each of the frames. The windowed data is placed column-wise in a data matrix. A fast Fourier transform is applied to the data matrix representing a piece-wise short-time Fourier transform (STFT) of the original signal. The operation results in a matrix containing time-frequency information about the signal. Two matrices, one containing the phase information and one containing the magnitude information are then formed. A periodogram is formed for each column of the magnitude matrix, yielding peaks indicating the presence of sinusoidal elements. Peaks below a threshold value are eliminated, and the remaining peaks are compared to the nearest frequency bins. These form frequency tracks if the peaks are located in adjacent bins.

The synthesis operation of the sinusoidal algorithm involves interpolating the amplitude and phase functions between frames, generating a sine wave for each identified frequency track. The resulting waveform is a summation of the sine waves. Phase unwrapping is incorporated to ensure that the frequency tracks are smooth. Applying these principles to a group of waveforms involves combining the magnitude matrices, phase matrices, and peak location matrices belonging to the individual waveforms. The synthesis operation of the sinusoidal model is shown in Figure 2.

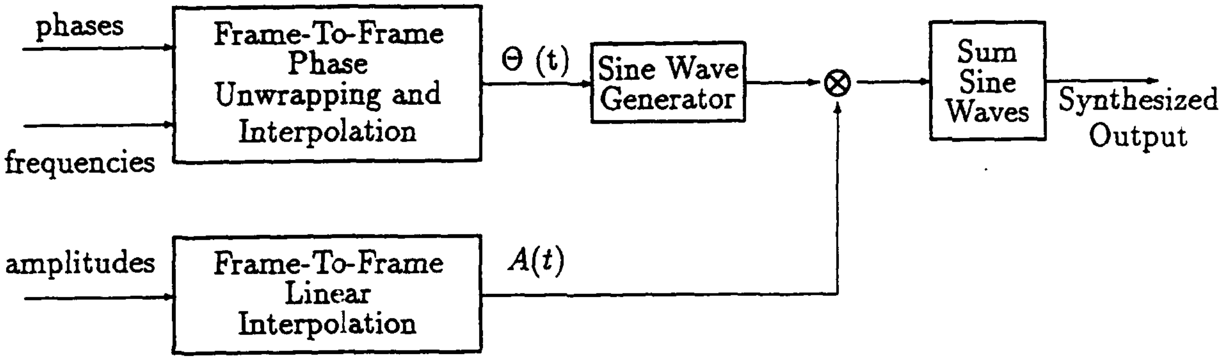

Figure 2: Synthesis Block Diagram

The sinusoidal modeling process can be thought of in the following steps: (1) Windowing and data formatting; (2) Short time Fourier transform; (3) Periodogram and peak picking; (4) Candidate Selection and frequency matching; (5) Frame-to-frame amplitude interpolation; (6) Frame-to-frame phase unwrapping and interpolation; (7) Sine wave generation and summing.

An example of the waveform combination using the sinusoidal algorithm is shown in Figure 3. The original signals, labeled A, B, C, and D are combined using this technique, and the resulting composite signal is shown as E.

<u>Discrete Wavelet Transform</u>

The STFT, as used in the sinusoidal modeling algorithm has drawbacks. The STFT uses a fixed window size (constant analysis bandwidth); therefore, the time-frequency resolution is fixed over the time frequency plane. The estimate is not as accurate at low frequencies but improves as the frequency increases. Wavelet transforms provide better frequency resolution at low frequencies and better time resolution at high frequencies. The time-frequency window is flexible, such that it automatically narrows at a high center frequency and widens at a low center frequency. The Discrete W···elet Transform (DWT) was developed for processing discrete-time signals [4], [5 ·VT as applied to EMP signals was performed by [1] and [3], and Figure 4 dep.. .. the decomposition scheme of the DWT. The original signal $x(n)$ can be decomposed by convolving it with a lowpass filter $h(n)$ and subsampled by two. At the same time convolving with a highpass filter $g(n)$ produces wavelet coefficients which are retained for reconstruction of the original signal. The decimated lowpass filtered signal of the finest level, M, is also retained.

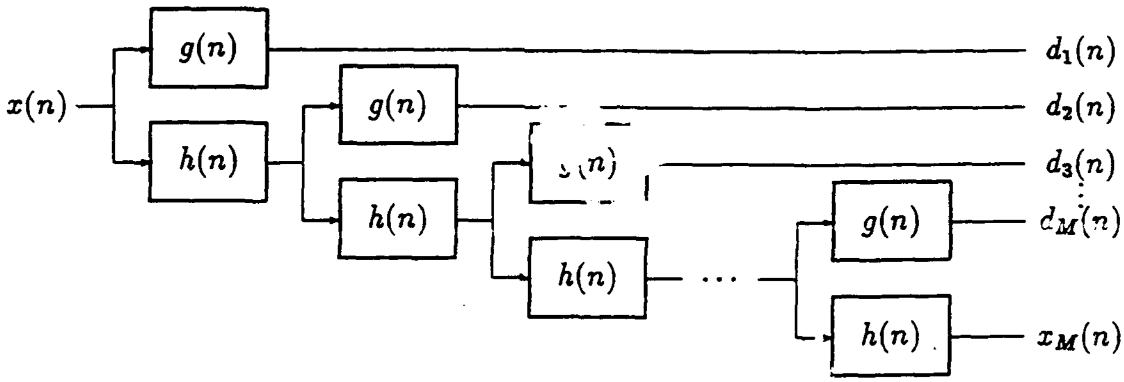

Figure 4: DWT General Decomposition Algorithm

The multi-resolution signals with the highest energy from each of the resolution levels (containing the high frequency information) and the finest level decimated signal (containing the low frequency information) are used to reconstruct a bounded composite waveform. Results of the DWT are shown in Figure 5. Note that the same base set of test point responses was used for both the Sinusoidal Modeling and DWT.

<u>Combined Sinusoidal Modeling Algorithm and DWT</u>

The Sinusoidal modeling algorithm and DWT produce composite waveforms that contain significant features of the original set of responses. The Sinusoidal modeling algorithm produces a composite signal that closely bounds the original set of responses to approximately 50 MHz. This is due primarily from the shortfalls of the classical STFT and the constant analysis window bandwidth. DWT produces a signal that closely bounds the original set of responses from approximately 50 to 100 MHz. This can be attributed to the DWT's use of a varying analysis window bandwidth. A concept of using a combination of Sinusoidal Modeling and DWT algorithms has been devised to exploit the significant characteristics of both approaches [1]. This process can be explained as follows: (1) Apply DWT decomposition to each of the four waveforms; (2) Combine results using sinusoidal modeling; (3) Reconstruct the synthesized waveform using DWT reconstruction. The results of the hybrid DWT/Sinusoidal method are shown in Figure 6.

Conclusions

In this paper we have presented two techniques for waveform combinations. The hybrid method, which combines the features of these two techniques, is also included. Norm attribute measures [6] have been used to compare the effectiveness of the combination techniques. The composite waveforms generated retain the worst-case norm attributes of the original set of responses.

The bounded electromagnetic stress envelope provides the maximum stress waveform by combining data gathered from multiple aircraft/threat scenarios. Examples include multiple orientations and configurations during high level pulse testing, low level continuous wave and computational analysis. Benefits include a better estimate of the maximum strength at a test point, higher confidence in test results, and improved performance of direct drive capabilities.

References

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A

B

C

D

E

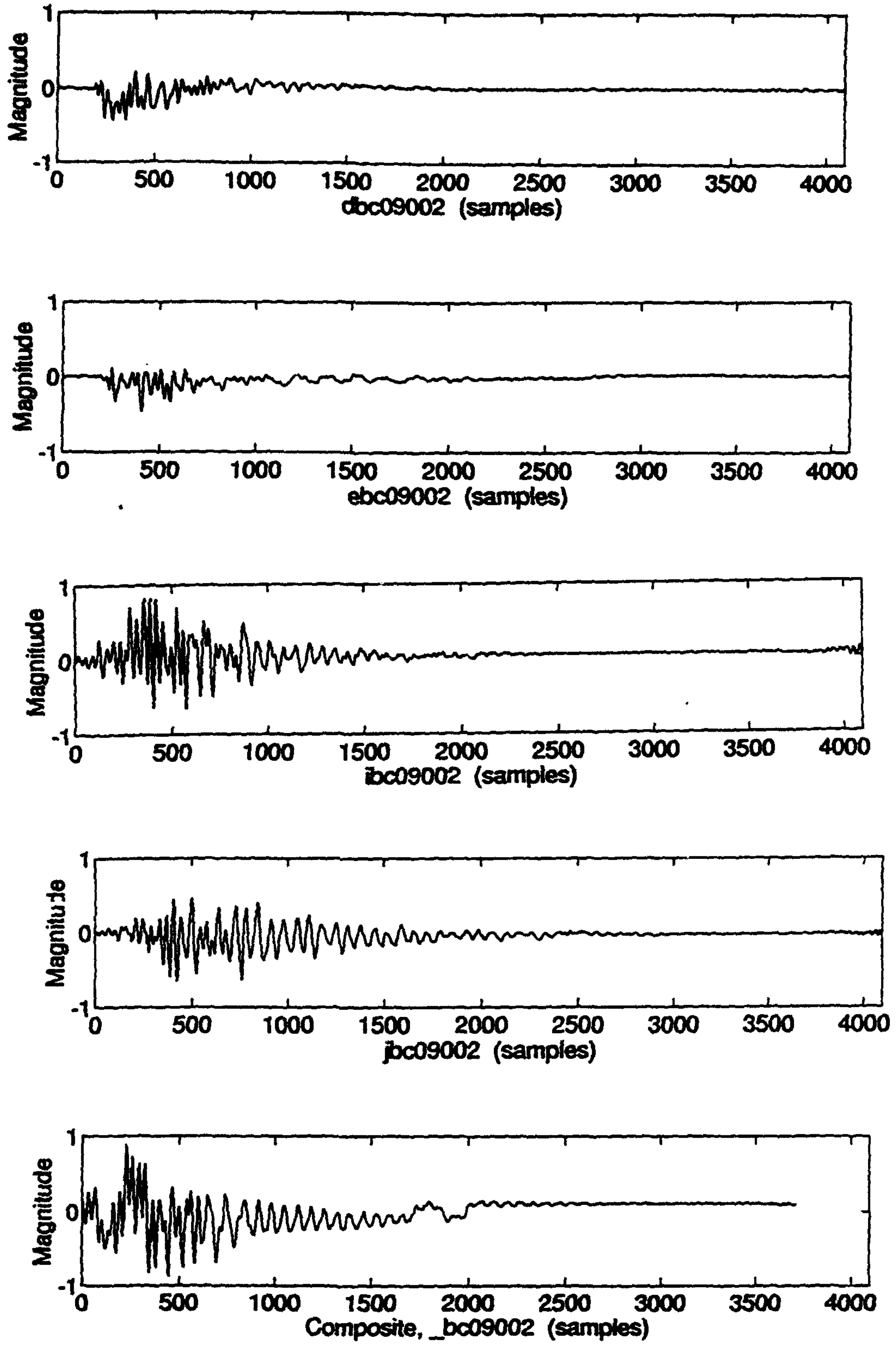

Figure 3: Example of the Sinusoidal Combination

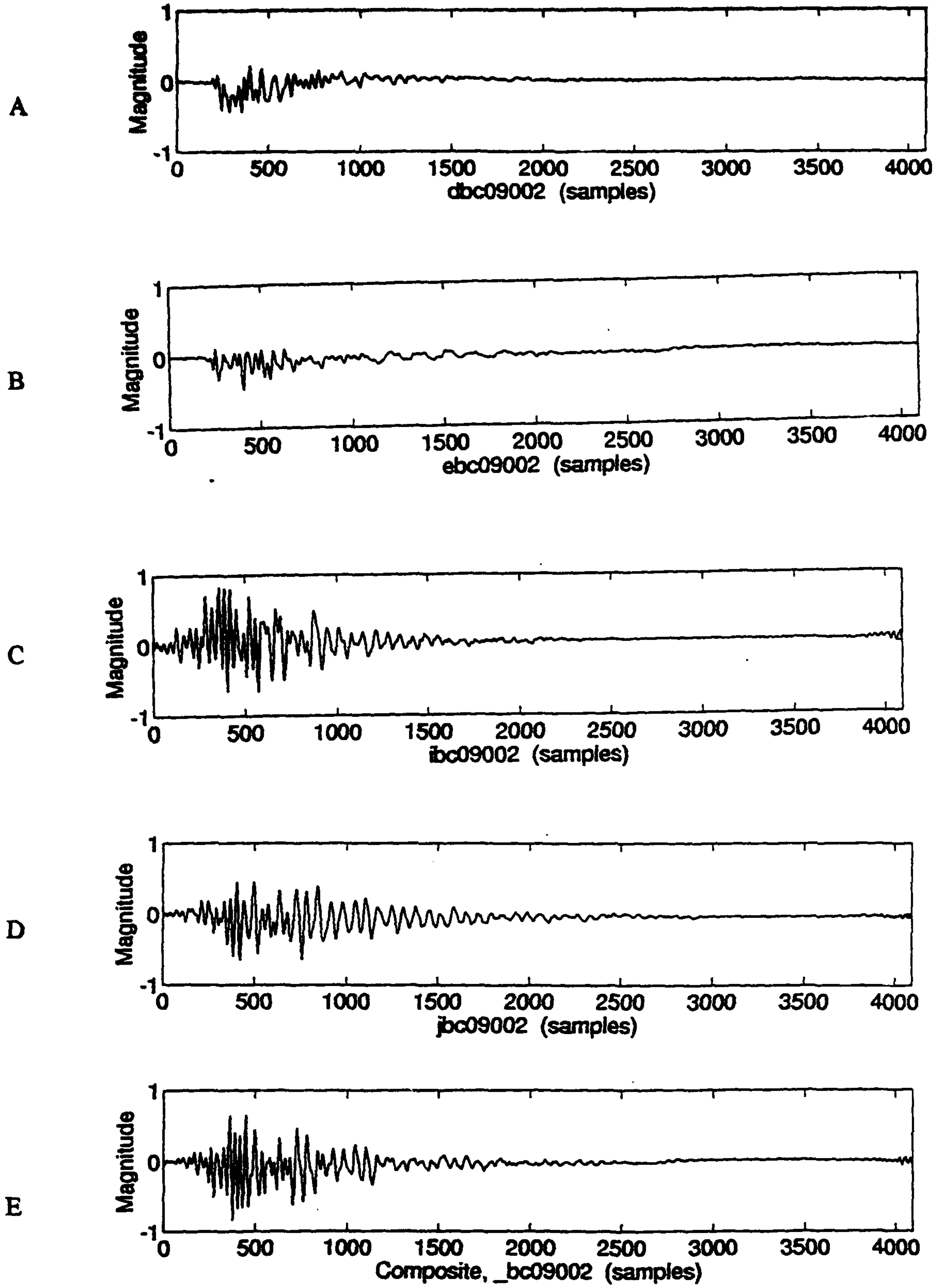

Figure 5: Example of the DWT

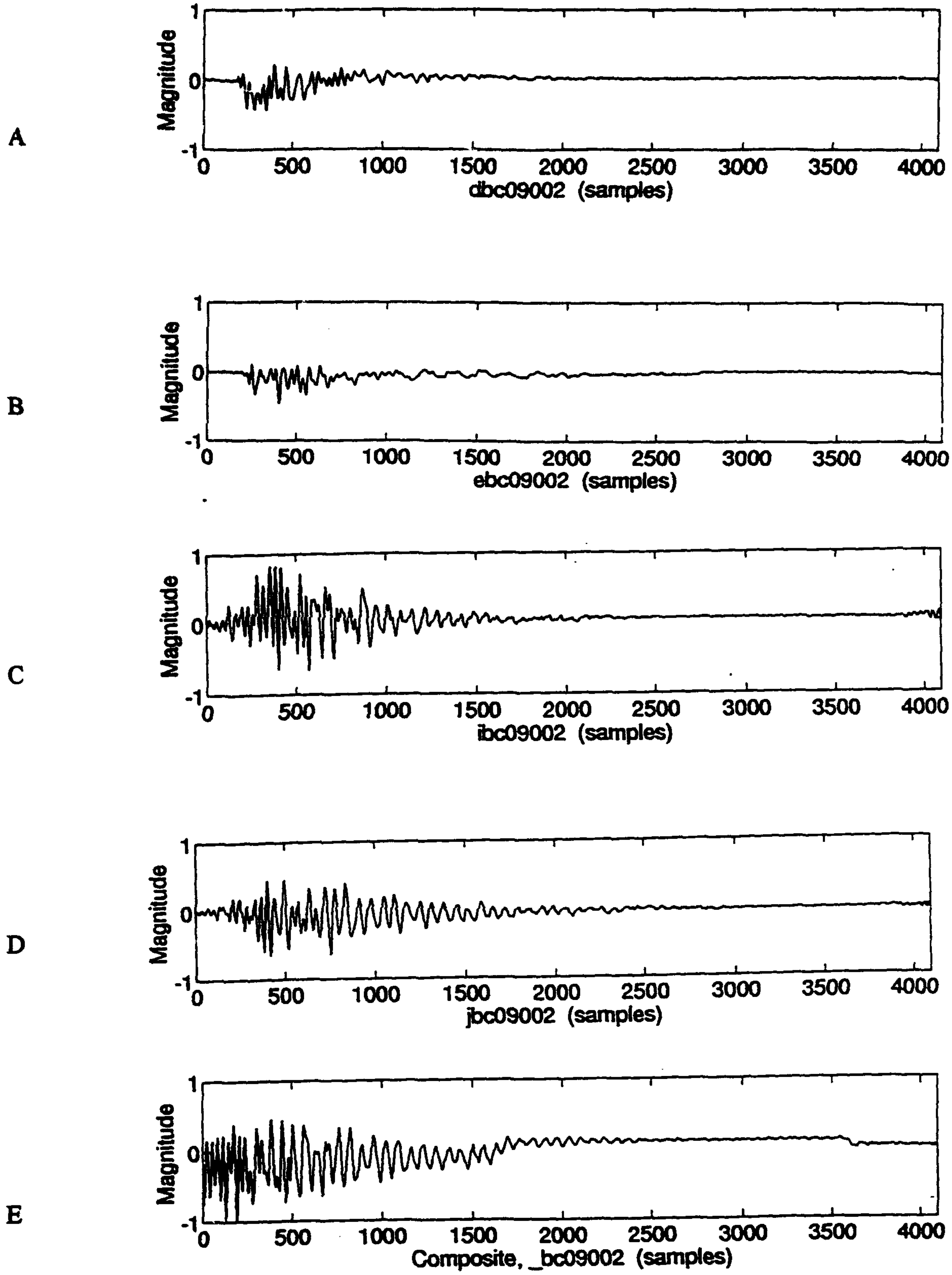

Figure 6: Example of the Hybrid